ON THE SPECTROSCOPE AND ITS APPLICATIONS

IX.

NOW let me state to you how the discovery mentioned on p. 12 was finally established by Kirchhoff. In my notice of the spectroscope in the earlier articles, I had so much to say that there were several details it was absolutely essential I should curtail. One of these details was the scale by which the positions of the different bright or dark lines which are seen in the different spectra are registered, so that we may say that such a line occupies such and such a position, and such another line occupies such another position, with regard to something else.

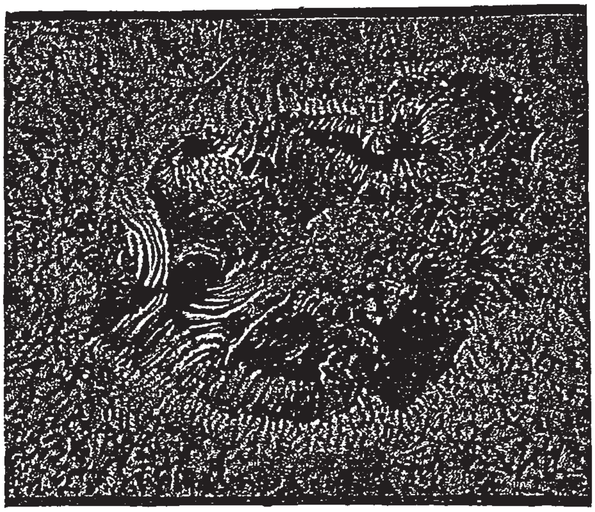

FIG. 50.—A sun-spot (Secchi), showing the "straws" in the penumbra, and the irregular masses on the general surface.

When Kirchhoff and Bunsen, two German chemists, were engaged in mapping the spectra of the elements—a research which at its commencement had nothing whatever to do with the sun—they came across this difficulty of a scale. How could they get a good scale? I have already referred to some very obvious arrangements that might determine the actual position; for instance, the observing telescope may be made to move along a graduated arc, so that by moving the telescope for the different rays and fixing it when in a proper position to see a particular ray, you might read off the index placed on the arc to a great nicety by means of a graduated *vernier* working on the curve of the arc; or you may, by a modification of the instrument, use a reduced photographic picture of a scale, so that the thing to be measured and the actual scale would appear in the field of view at the same time.

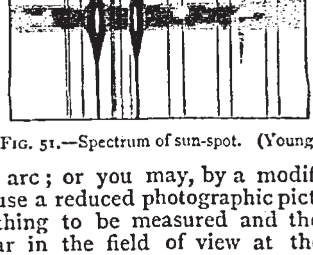

FIG. 51.—Spectrum of sun-spot. (Young.)

Kirchhoff and Bunsen tried these methods, but they did not like them. Then it suddenly struck them that, as they made their experiments in the day-time, they might use as a scale the black lines in the solar spectrum, which had not been known to change since the time of Wollaston, who discovered them. When working in the daytime, they had thus the solar spectrum visible in one half of the field of view of the telescope, which was easily managed by placing a reflecting prism over one half of the slit, as is shown in the enlarged slit in Fig. 46, so as to light one half of the slit by the sun, and the other half by whatever substance was under examination. With this arrangement they set to work with infinite care, and made a map of the solar spectrum. Such was their proposal: first to map the unchangeable solar spectrum, and then, having this unchangeable scale, about which there could be no mistake, always visible, they would be able to refer to the dark lines in it all the unknown phenomena they were about to investigate in the bright lines of different vapours and gases. Having got this idea of the scale well into their minds, they were exceedingly anxious to test this question, which, as I have told you, was raised by Fraunhofer and many other men before them, of the asserted coincidence of the bright sodium line with the dark solar sodium lines; with a very delicate instrument, Prof. Kirchhoff made the following remarkable experiment:—"In order," says Kirchhoff, for these are his own words, "to test in the most direct manner possible the frequently asserted fact of the coincidence of the sodium lines with the lines D"—(that is to say, of the bright double lines of sodium in the yellow part of the spectrum, with the double line D of the solar spectrum)—"I obtained a tolerably bright solar spectrum, and brought a flame coloured by sodium vapour in front of the slit. I then saw the dark lines D change into bright ones."

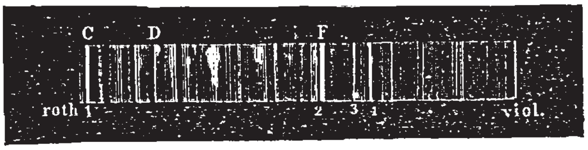

FIG. 52.—Spectrum of τ Coronæ. (Huggins.)

That is to say, in the spectrum of the sodium which was burning in the flame were lines so exactly coincident with the two dark lines in the solar spectrum, that the bright lines of the sodium spectrum put these dark lines out altogether, so that they seemed to vanish, as it were, from the solar spectrum. He goes on:—"In order to find out the extent to which the intensity of the solar spectrum could be reduced without impairing the distinctness of the sodium lines, I allowed the full sunlight to shine through the sodium flame."

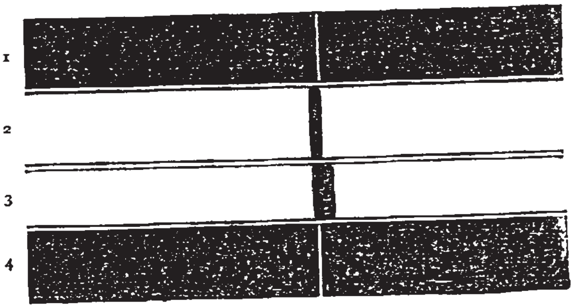

FIG. 53.—Alteration of wave-length of the hydrogen in the atmosphere of Sirius. 1, Hydrogen at atmospheric pressure; 2, Solar Spectrum Line F; 3, Spectrum of Sirius; 4, Hydrogen in vacuum tube.

Here he varies the experiment. In the first instance he used a very feeble beam of sunlight, but he now allows the whole glare of the sun to enter the slit. What was the result? "To my astonishment, I saw that the dark lines D appeared with an extraordinary degree of clearness." That is to say, the lines which came from the sodium in the first instance, were sufficiently bright to entirely eradicate the dark lines from the solar spectrum, but the two lines D were now so utterly powerless compared with the light of the sun, that they actually appeared as black lines, and coincident with the two lines D in the solar spectrum.

We have seen that the bright line due to the radiation from sodium vapour can be very easily obtained by placing some sodium in a colourless gas flame, but if we now pass the continuous light coming from the carbon points of an electric light, or from the oxyhydrogen lime-light, through this same sodium flame, the result will be that we obtain a black absorption line on a continuous spectrum, in precisely the same position as the yellow line was originally. This is Kirchhoft's crucial experiment, which at once determined not only that the dark line in the sun was absolutely coincident with the bright line of sodium vapour, but that, under certain conditions, bright, incandescent sodium vapour could actually be made to absorb the light coming through it, and reverse its own spectrum. Kirchhoff goes on:—"I then exchanged the sunlight for the Drummond or oxyhydrogen lime-light, which, like that of all incandescent solid and liquid bodies, gives a spectrum containing no dark lines." When this light was allowed to fall through a suitable flame, coloured by common salt (or chloride of sodium), dark lines were seen in the spectrum in the position of the sodium lines." You may imagine that this conclusive experiment—perhaps the most wonderful experiment that has been made during the century—gave Kirchhoff food for thought, and at once his genius travelled to a possible explanation of this strange fact he had observed; a fact, as you know, entirely in accordance with the previsions of Prof. Stokes, Dr. Balfour Stewart, and Foucalt. Kirchhoff said to himself, "I have now got the bright lines in the spectrum of the vapour of sodium coincident with the two dark lines in the solar spectrum. What does it mean?" And again the philosopher was not at fault. He said to himself—it is almost possible to see the train of his reasoning in his memoirs—"Sodium has a most simple spectrum; suppose I take the most complicated spectrum I can find." He took for this purpose the spectrum of iron, which I think you will acknowledge to be one of sufficient complication, for the spectrum is traversed by lines throughout its whole length, and I may tell you at once that no less than 460 lines have been already mapped, and their positions are now thoroughly well known to us—as well known as the position of any star in the heavens. Kirchhoff tried the iron spectrum, and he found, absolutely corresponding in position in the spectrum and in width and darkness to the bright iron lines which he saw, black lines in the solar spectrum. He waited no longer; he instantly convinced himself, and soon convinced the world, that he had discovered this very remarkable fact, that gases and vapours have the power of absorbing those very rays which they themselves give out when in a state of incandescence. So that, if you take sodium, and get its bright lines, and mark their positions on the screen, and then observe a continuous spectrum, and interpose sodium vapour in the path of the beam, you will find black lines absolutely corresponding with the bright ones; that is to say, that the sodium vapour has the faculty of entirely eating up, absorbing, or stopping that light which would otherwise go on to the screen. In the case of iron, it is worthy of notice that when Kirchhoff made his discovery, he was only able to obtain a spectrum of iron consisting of something like 90 lines, but since then the spectrum of iron has been mapped to the extent of 460 lines, and sure enough there are solar lines corresponding to nearly all the 460 bright lines which we are able to get in our laboratories. Not only was the bright line of sodium *reversed* or changed into a dark one, but it was soon found that the lines of other metals, such as lithium, potassium, strontium, calcium, and barium, could be reversed in a similar manner. This grand discovery of Kirchhoff's met with immediate acceptance, and with it you see at once the explanation of the wonderful black lines discovered by Wollaston, about which I said something in my first lecture. The riddle of the sun was read to a certain extent, and Kirchhoff read it in this way. He said:—"There is a solid or a liquid something in the sun, giving a continuous spectrum, and around this there are vapours of sodium, of iron, of calcium, of chromium, of barium, of magnesium, of nickel, of copper, of cobalt, and aluminium; all those are existing in an atmosphere, and are stopping out the sun's light. If the sun were not there, and if these things were observed in an incandescent state, we should get exactly these bright lines from them." Later researches by many distinguished physicists have shown that the following terrestrial elements are present in the vaporous condition round the sun:—

1. Sodium.
2. Calcium.
3. Barium.
4. Magnesium.
5. Iron.
6. Chromium.
7. Nickel.
8. Copper.
9. Zinc.
10. Cadmium.
11. Cobalt.
12. Hydrogen.
13. Manganese.
14. Aluminium.
15. Titanium.

Kirchhoff further imagined that he had reason to believe that the visible sun, the sun which we see—and we may take the sun as an example of every star in the heavens—was liquid.

In the sun we have, first, a bright, shining orb, dimmed to a certain degree at the edge; and here and there, over the sun, we see what are called spots. Kirchhoff wished, not only to connect his discoveries with the solar atmosphere, but was anxious to connect them with this dimming near the limb and the spots. He said that the solar atmosphere, to which all the absorption lines were due, extended far outside the sun, and formed the corona; and that this dimming of the limb was really due to the greater absorption of this atmosphere, owing, of course, to the light of the sun travelling through a much greater length at the limb than at the centre of the disc. Furthermore, he said that the sun-spots, which astronomers, from the time of Wilson, had asserted to be cavities, were nothing but clouds floating in this atmosphere of vapour. Such was the very bold hypothesis put forward by Kirchhoff—an hypothesis which you see at once explains these strange observations from Wollaston upwards, including Fraunhofer's observation of the spectrum of the sun and stars, and the brilliant ideas of Prof. Stokes, Dr. Balfour Stewart, and others in other lands. A little simple experiment, made by means of a little sodium vapour and a beam of sunlight, with the powerful aid of a little prism, gave us this tremendous knowledge about distant worlds so immeasurably remote that it seemed absurd for men to try and grapple with any of the difficulties that are presented to us. Such, then, is Kirchhoff's theory of the sun, which I hope I have been able to make clear to you. There is a something—Kirchhoff said it was a liquid—which gives us a continuous spectrum, and between our eye and that incandescent liquid surface there is an enormous atmosphere, built up of vapours of sodium, iron, and so on; and the reason that we get these dark lines is, that the molecules of the substances named absorb certain rays, because when they are in an incandescent state they produce them. This brilliant idea of Kirchhoff's was soon carried, as you know, to the stars by Mr. Huggins in our own country. In Fig. 34 will be seen the spectra of two stars, Aldebaran and α Orionis (Betelgeux), which are so distant that it is absolutely impossible to measure their distance from us. We know a great deal about our own sun, but these suns are so lost in the depths of space that it is quite impossible that we can get anything like a correct knowledge of their size, or know much of their belongings. By means of the prism, however, we learn in a moment a great deal. In the first star we get three lines, due to the absorption of magnesium vapour, as we get them in the sun. We know, therefore, that magnesium vapour is present in the atmosphere around that sun (Aldebaran) in exactly the same way as round our own. We also get some of the iron lines, the lines of sodium, and the lines of hydrogen, calcium, and a few other elements—nine in all. At the base of the diagram you see indications of the elements, with the bright lines of which Mr. Huggins has compared the black lines which you see in the spectrum of these heavenly bodies. By means of the star spectroscope and of the induction coil, Mr. Huggins tested these lines, as Kirchhoff did in the case of the sun, by actually getting the vapour of magnesium visible at the same time in the spectroscope: and thus you see in a moment that there is no difficulty at all in determining their coincidence, you have the two things brought so closely side by side. If I had time I might remark on the presence of some elements here and the absence of others; but there is one remarkable fact about this lower star (*a* Orionis) which I must mention. As far as its spectrum goes, it appears that the gas hydrogen, which is a very important element in our sun's atmosphere, as we gather from the great distinctness of the hydrogen lines in the solar spectrum—and not only in our sun, but in a great many others—is absolutely absent, whilst magnesium, sodium, calcium, &c., are present.

So far, then, you see that this little prism has enabled us to read a great many secrets of the sun and of the more distant stars; and we must acknowledge that Stokes' and Kirchhoff's hypothesis is a very magnificent one, and we can but wish that there were more men like them, who, undismayed by the failure of those who, for nearly a century before their time, had been endeavouring to unravel these secrets, were still prepared to go on, and endeavour to find them out by means of a prism and a simple sodium flame.

Now, astronomers—who, as I told you, from the time of Wilson had imagined that the sunspots were cavities—very soon began to quarrel with this hypothesis of Kirchhoff's, who said that the sunspots, instead of being cavities, were really clouds floating in the atmosphere. They remarked, and I think with truth, that to make such an assertion was altogether opposed to the evidence of the telescope. And I think I may say that the astronomers have now carried the day, for another line of independent research altogether—I mean the researches into the constitution of the sun by means of the spectroscope—has come to the aid of the astronomers, and it looks very much as if we must still hold to the opinion that Wilson in his observations, now more than a century old, was perfectly right, and that Kirchhoff's analysis, as far as it deals with the sun-spots, is susceptible of improvement. In the remarks I made in my former lecture on radiation in connection with the red prominences visible during eclipses, I drew your attention particularly to the hydrogen lines, and told you that the red flames are, for the most part, composed of hydrogen. There the prism comes to our aid in a very remarkable way indeed. It is clear to you, I think, after what I have said about absorption, that the darkening of the sun's surface, which we call a spot, is really a thing about which the prism can tell us a great deal. For instance, take a sun-spot, in which the usual brilliancy of the sun in the other parts of its disc is altogether wanting. There is not only great darkness here and there, but wonderful turnings and twistings and bendings of this solar envelope, which I have already told you Kirchhoff asserts to be a liquid one, but which I think a little consideration of Fig. 50 will show you is more probably gaseous, or cloudy, than liquid. It is obvious, I say, in this case that there was a great probability of the spectroscope being able to tell us something about this absence of light, for an absence of light means one of two things; it means either that there was a defect in radiation, or that there was some excess of absorption, and I may say that this difference—which I hope you now all thoroughly understand—really formed the battle-ground between the English and French astronomers until a few years ago. Long after Kirchhoff's experiment, M. Faye, a distinguished member of the Institute of France, went all over the work again, and declared that the sun-spot was dark, because we there got the light, not from the brightly shining envelope, but from some feebly radiating gas inside the sun; that the sun was a gigantic bubble, the bubble being nothing else than the photosphere—the liquid sphere of Kirchhoff—the interior being composed of gas, glowing at such an enormous temperature that the light we got from it was extremely feeble. You will see in a moment that, if the sun-spot were really due to the radiation from gas, we should get from that sun-spot a selective spectrum, that is to say, a spectrum with bright lines. The English astronomers said: "No; a sun-spot is not due to defective radiation at all; there is something over the bright portion of the sun which eats away the light:" whether the light was eaten away generally—whether, in fact, we had an instance of general or selective absorption—was not stated, but what they did distinctly state was, that the sun-spot was simply an indication of absorption. So that, you see, here was a thing which a spectroscope might settle almost at once, provided always that a good sunspot could be obtained for the experiment. This was done in 1866. Fig. 51 gives an idea of what is seen when we observe a small sunspot, and it is one which is full of meaning. Here is a very clear image of the solar spectrum near the double line D, and also the double D itself. If it were possible to have given you the whole of the sun's spectrum on the same scale as this, it would require an engraving yards in length, but it would be almost impossible to make my meaning clearer than I hope I can do by this small portion; and I must therefore ask you to take for granted that the dark line which you see running along this yellow portion of the spectrum would really run along the whole length of the spectrum, from the extreme red to the extreme violet. This, then, you see in a moment, was an indication of general absorption; that is to say, in the way in which the light is affected by its passage through the prism, we have the problem settled in an instant, that a sunspot is due to general absorption at all events. Further, in observing the spectra of different sunspots, it was found that the spectrum of the middle of the sunspot is much darker than the outside. So that you see this simple experiment tells us not only that the sunspot is due to general absorption, but that there is more general absorption in the middle of the spot than at its edge. This is the way in which this little prism is able to deal with these great problems.

J. NORMAN LOCKYER

(*To be continued.*)

MIND IN THE LOWER ANIMALS

I RECENTLY received a letter from Mons. J. C. Houzeau, the author of the "Études sur les Facultés Mentales des Animaux comparées a celles de l'Homme," published at Mons, Belgium, in 1872, and reviewed by Mr. Wallace in NATURE of October 10, 1872. The latter eminent writer asserts that M. Houzeau's work "contains a mass of curious facts, acute observations, and sound reasoning, which fully entitle its author to take high rank among philosophical naturalists" (p. 471). I quite agree with him in his estimate of M. Houzeau's labours, being disposed to place his two volumes of "Études" on a par with the works of Mr. Darwin; and with another work, which, while little, if at all, known in this country, deserves, nevertheless, the highest consideration at the hands of all interested in comparative psychology—the "Traité de la Folie des Animaux de ses Rapports avec celle de l'Homme," by Dr. Pierquin, published in Paris (in 2 vols.), so long ago as 1839.